Development of the Crotch Absorbers for ALBA Storage Ring

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Abstract

The ALBA Synchrotron Light Facility is a third generation light source with a storage ring of 268.8 m in circumference. Its beam energy and design current are 3 GeV and 400 mA respectively. With the design current, a total power of 407 kW is radiated by the circulating beam from the bending magnets. Only a small part of the bending magnet radiation will be extracted to the beamlines and absorbed by particular components in the storage ring; while the others will be intercepted by the "crotch absorbers".

In ALBA several design criteria have been investigated in order to create our crotch absorber which is based on the number of allowed cycles before failure with the concept of the strain values. In absorber design, many aspects have been carefully considered including the stress, strain, maximum overall temperature and maximum cooling temperature. Finite Element Analysis (FEA) and Computational Fluid Dynamics (CFD) have been performed using the ANSYS software.

Three crotch absorber prototypes have been designed and manufactured. In total 156 crotch absorbers are needed all around the machine in order to guarantee that no radiation will hit the chamber walls.

This paper deals with the aspects related with the development of the crotch absorbers for ALBA storage ring: treatment of the bending magnet radiation, design criteria, FEA results, cooling improvement by using CFD and hydraulic tests for real models.

1. Background

The ALBA Synchrotron Light Facility is a third generation light source under construction near Barcelona (Spain). For the machine design the beam energy and design current are 3 GeV and 400 mA respectively. The circumference of the storage ring is 268.8 m, the vacuum chambers are made of stainless steel with antechambers, where crotch absorbers are placed to remove the unused radiation [1].

In the storage ring the bending magnet (BM) radiation is a beam of radiation generated by each 32 dipole magnets. The BM radiation flux varies slowly in the horizontal direction (i.e., in the plane of the storage ring) and follows a nearly Gaussian profile vertically. Each of the 32 bending magnets produces a fan of radiation with opening angles of about 196.4 mrad horizontally. A total power of 407 kW is radiated by the circulating beam from the bending magnets.

Most of the synchrotron radiation generated by the bending magnets is absorbed in the crotch absorbers (around 95%) and the rest of the power is absorbed by Front Ends and special components. An important challenge in the engineering of the crotch absorbers is the ability to withstand the temperature and thermal stress induced by the high heat load in the component materials within the accepted safety limits. While the total power could cause serious consequences, it is often the power density that sets up thermal gradients in the material causing excessive thermal stresses and deformations. For the critical crotch absorbers the peak linear and surface power densities at normal incidence are about 64.4 W/mm and 246.2 W/mm^2 respectively, and the maximum total power is about 6.78 kW. Due to this thermal load, the crotch absorber must be carefully designed to guarantee longevity and good performance. Hence extensive work has been conducted on various thermal and structural aspects of the design.

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The ALBA crotch absorbers follow the original design done at PSI for ANKA crotch absorbers [2] with some modifications in order to improve the thermal and mechanical function of the absorber. Finite Element Analysis (FEA) has been performed to estimate the stress, strain, maximum overall temperature and the maximum cooling temperature for all the types. Computational Fluid Dynamics techniques (CFD) have been also included in the investigations in order to improve the performance of the cooling pipe at critical regions.

2. Basic Design

The geometry is based on the original design done for ANKA absorbers [2]. Some modifications to this design have been implemented in order to improve the thermal and mechanical function of the crotch absorbers. The complete model of the crotch absorber consists of two parts (the upper and the lower jaws). Each jaw is formed by a row of teeth and every tooth has the same configuration in each jaw (see Figure 1).

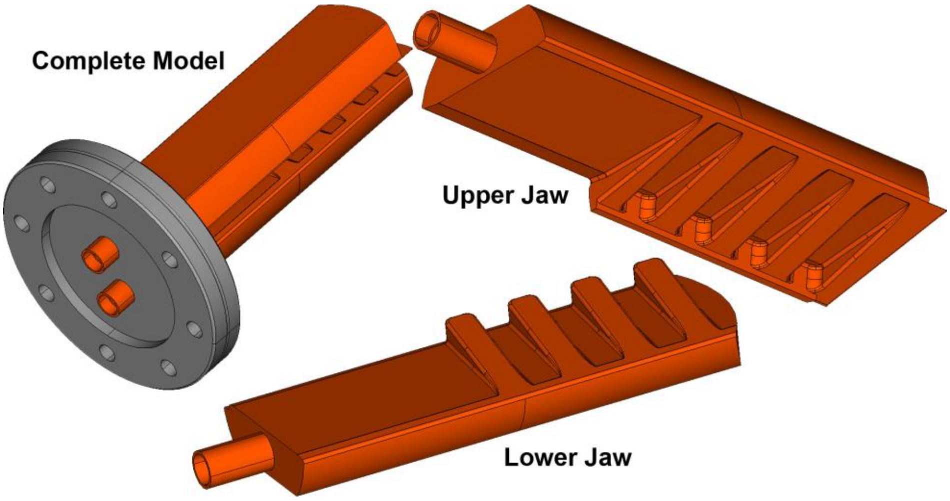

Figure 1 Basic components of the crotch absorber. The complete model consists in two parts: the upper and the lower jaws which are connected by a flange. Each jaw is formed by a row of teeth.

For the ALBA design fillets of 1 mm were included on edges parts in order to reduce the thermal stresses [3]. A minimal distance between the internal wall of the cooling channel and the external surface of the crotch absorber (vacuum zone) has been fixed for the design (> 3.5 mm) (see Figure 2a). The distance between the end of the pinhole and the end side of the crotch absorber was chosen to be 7.5 mm in order to attenuate the possible effects of corrosion – erosion, which will be higher at the end of the pinhole (see Figure 2b). All the teeth are inclined by 5º with respect to the width of the crotch absorber (see Figure 2c); this optimal angle improves the absorption of the radiation in between the jaws because the inclination increases the internal reflections of the beams. As a rule of thumb a minimal distance of 2.5 mm has been defined between the internal walls of the pumping port and the end of the crotch absorber (see Figure 5d). In some positions of the storage ring, the end of the crotch absorber crosses the limits of the internal wall of the pumping port; in these cases the crotch absorber need to have a circular end with a "special tooth", which is located in the internal part of the electron beam channel of the vacuum chamber (outside of the pumping port) (see Figures 2d and 2e). The main function of this "special tooth" is to have a safe system to stop the first component of the fan radiation. The height of this "special tooth" was chosen to be 8 mm because on this location the height of the internal vacuum chamber equals 10 mm. In some positions of the storage ring the absorbers have an opening to permit the radiation coming from Insertion Devices and/or Bending Magnets to pass to the experimental lines. At the upper jaw, the teeth are connected in the back side by a cover which its main function is to absorb the possible remaining reflections of the radiation which hit the absorber.

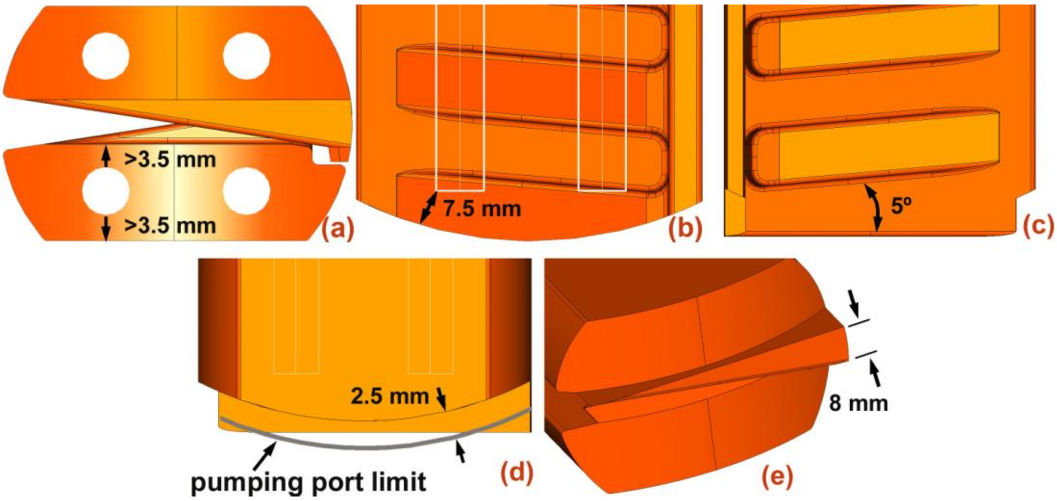

Figure 2 Some geometrical guidelines for the dimensioning of the ALBA crotch absorbers. (a) Minimal distance between the internal wall of pinhole and the external surface of the body (vacuum zone). (b) The distance between the end of the pinhole and the end side of the crotch absorber. (c) The horizontal angle of inclination for each tooth. (d) The minimal distance between the end side of the crotch absorber and the internal wall of the pumping port. (e) Details of the "special tooth" for some particular crotch absorbers, the height is fixed to be 8 mm for all cases.

The crotch absorbers have been grouped into 3 types (see Figure 3). The material type is based on the thermo–mechanical behaviour of the absorbers. The types 1 and 2 are made of Oxygen Free High Conductivity OFHC copper and the type 3 is made of Glidcop® Al-15. The cooling is formed by a number of pinholes; this number depends on the type of absorber. The absorber types 1 and 2 receive moderate amount of power, the width of the teeth on these absorbers is 10 mm and the vertical angle of inclination of each tooth (with respect to the plane of radiation) equals 8.8º, this reduces the power density at normal incidence by about 85 %. The distance between the teeth is 11 mm (this will keep a clearance of 0.5 mm to each side of the tooth and will allow space for possible expansion due to the heating from radiation). The absorber type 1 has two pin holes and the type 2 has 4 pin holes. Absorber type 3 is the main (critical) absorber, this type of absorbers will take the radiation from the dipole which is installed inside it or just after it (close to the source point of the radiation) and the power there is the highest with respect to the other types. In order to reduce the total strain and to increase the number of cycles, the thickness of the teeth is 6 mm and the distance between the teeth is 7 mm. The inclination angle of the teeth is 6.6º (this inclination reduces the power density at normal incidence by 88.5%). Eight pinholes have been introduced to this critical absorber. In total 156 absorbers are needed all around the machine.

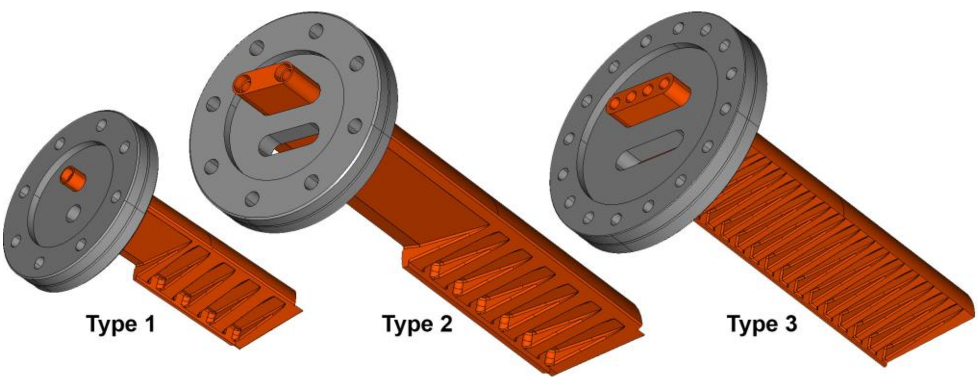

Figure 3 The three types of the crotch absorbers for ALBA (upper jaws). The types 1 and 2 are made of OFHC copper and the type 3 is made of Glidcop® Al-15.

3. The Design Criteria

A survey has been made to investigate the different design criteria being used at different accelerators. Several contacts with several laboratories and a collection of criteria from literature have been preformed [4]. Many design criteria have being adapted by each laboratory (see Table 1), however the majority pointed out that the fatigue is the source of failure for a crotch absorber, and so they used the cycles for fatigue as their design criteria and according to the number of cycles they have decided the strain and stress values. For ALBA, the crotch absorbers were, in general, designed respecting the commonly used criteria (Table 1), however the main decision was made that the cycles for fatigue based on the strain values for OFHC copper and Glidcop® Al-15 will be the design criteria for the material. To guarantee that the absorbers are safe for the life time of the machine, the material has been chosen for values more than $1x10^5$ cycles of OFHC copper (strain less than 0.1 %) and over $1x10^5$ cycles for Glidcop® Al-15 (strain less than 0.2 %).

Table 1: The design criteria for the crotch absorbers in several facilities.

Accelerator	*Thermal Performance*	*Structural Performance*
APS [5]	*Temperature of cooling water:* $T_{water} < T_{boil} = 150°C$ *at 5 atm* *Temperature of absorbing surface:* $T_{surf} < 0.5 \times T_{melt} = 541°C$ *for copper*	*Thermal Stress* (S_{TH}) < 2 x S_Y *(0.2% Yield Strength); and <* S_F *(Fatigue Strength) for* 10^5 *Cycles; and <* S_Y *(Hot) +* S_Y *(Cold)*
ESRF [6]	ΔT_{max}< *300 °C for Glidcop* ΔT_{max}< *150 °C for OFHC copper* *The maximum cooling wall temperature should be lower than water boiling temperature at the pressure of the water in the cooling tubes.*	*The maximum stress in the copper thermal absorber should be smaller than twice that of the ultimate tensile strength of the copper* (σ^{VM}_{max}<400 *MPa for OFHC copper,* σ^{VM}_{max}<850 *MPa for Glidcop).*
SOLEIL [7]	*Maximum temperature on the wall of the cooling channels T = 100 °C*	*Maximum thermal stress about 75 % of the material yield stress*
DIAMOND [3]		*For copper the strain is considered as criteria for the design limit: 0.5% peak strain (50 Mpa) and 0.1% (35 MPa) in the bulk body.*
ANKA, SLS [2]		*The strain for OFHC copper < 0.2 % which guarantee a 10,000 cycle.*
SPRING–8 [8]		*The cycles for fatigue are the design criteria and they used the strain.*

Reference [9] presents the low cycle fatigue behaviour of OFHC copper at 300°C in high vacuum. For brazed and unbrazed specimen and for two sizes (full size specimen is the ASTM recommended size for fatigue testing, and sub-size specimen has threaded ends with different geometry of the ASTM recommended size). The brazing was done for the specimens in hydrogen environment and the brazing cycle was 30 min soak at 980°C followed by 2 min hold at 1,025°C. Figure 4a shows the total strain as a function of the number of cycles to failure for OFHC copper. For ALBA, the results from “curve c” (for the ASTM full size specimen – brazed) have been used to determine the cycles for fatigue for the copper absorbers.

SPring-8 presented in reference [8] the cycles for fatigue for Glidcop using the strain, at different temperatures (100, 200, 400 and 600°C) for heat treated (800°C for 3 hours). Figure 4b shows the total strain as a function of the number of cycles to failure for Glidcop. For ALBA, the results from "total strain range_400" have been used to calculate the cycles for fatigue for the Glidcop absorbers.

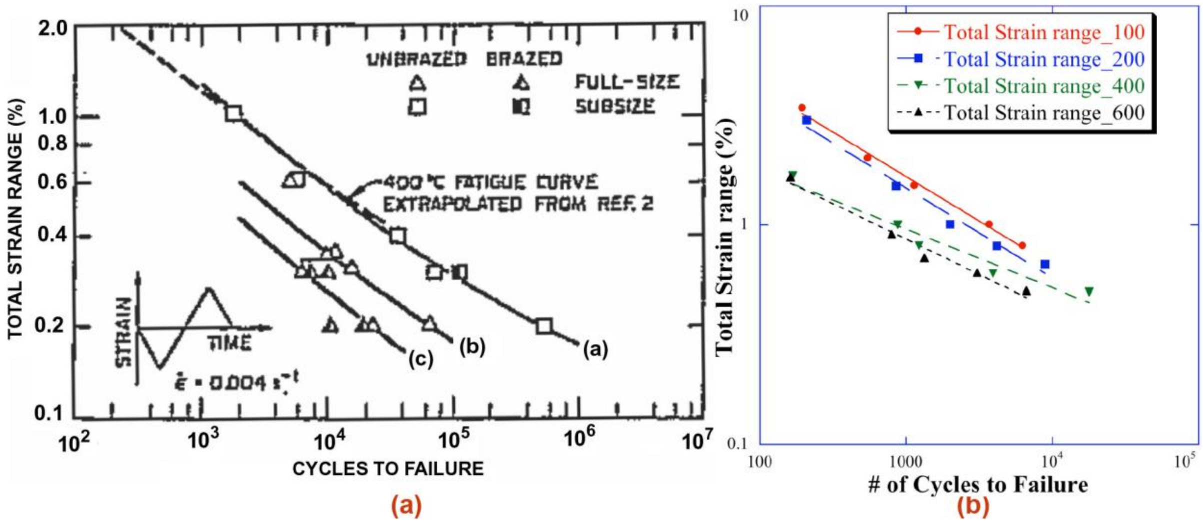

Figure 4 (a) Total strain range as a function of cycles to failure for OFHC copper at 300 °C tested in vacuum [9]. (b) Low cycle fatigue properties for Glidcop. Relationship between the total strain range and the number of cycles to failure at temperature of 100°C, 200°C, 400°C and 600°C [8].

4. Numerical Simulations

4.1. Power load conditions: application of bending magnet (BM) radiation

The bending magnet (BM) radiation is uniform in the horizontal direction (plane of the storage ring) and follows a nearly narrow Gaussian profile vertically. In the ALBA storage ring the BM radiation is generated by each of the 32 bending magnets, each covering an arc of about 196.4 mrad. With the design parameters (see Table 2) a total power of 407 kW is radiated by the circulating beam from all the bending magnets.

Because of its narrow vertical profile the footprint hitting on the absorbers surface spreads out in an extensively wider area along the horizontal direction than along the vertical direction (see example in Figure 5a).

For the power load calculations the vertical distribution of the radiation has been simplified by a conservative approach so that the area below the angular power density (64.8 W/mrad) is included in a rectangular area which is generated by keeping the highest point of the curve ("step function") (see Figure 5b). The width of this rectangle is called "the effective vertical opening". For ALBA this angle is 0.26 mrad.

For the ALBA critical crotch absorbers, the peak linear and surface power densities at normal incidence are about 64.4 W/mm and 246.2 W/mm^2, respectively, and the maximum total power is about 6.78 kW. Finally, the maximum projected power density on the critical crotch absorber is about 28 W/mm^2 at incident angle 6.6°. For all the cases we assumed that the incident beam power is deposited on the surface.

Table 2: Main parameters for ALBA Storage Ring which characterize the power on the absorbers.

Parameter	***Unit***	***Values***
Beam Energy, E	*GeV*	*3*
Design current, I	*mA*	*400*
Dipole magnetic field, B	*T*	*1.42*
Dipole magnets radius of curvature, ρ	*m*	*7.047*

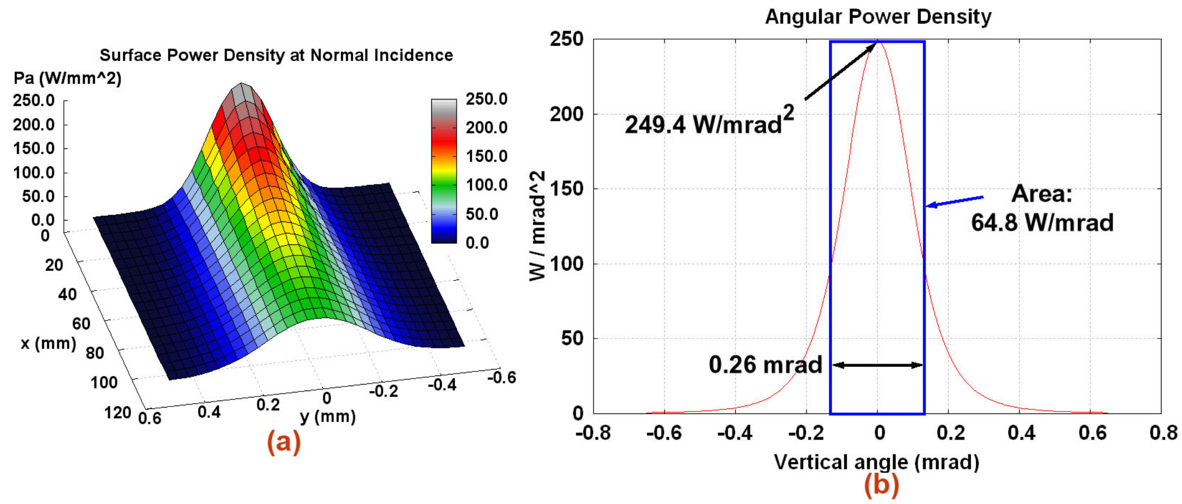

Figure 5 (a) Example of how the footprint heating on the absorbers surface spreads out in an extensively wider area along the x–horizontal direction than along the y–vertical direction. (b) The angular power density (nearly Gaussian profile) versus the vertical angle for bending magnet radiation. For the thermal boundary conditions a conservative approach is made: a constant opening angle in the vertical direction is fixed considering that the area below the angular power density (64.8 W/mrad) is included in a rectangular area, which is generated by keeping the highest point, then the effective vertical opening is 0.26 mrad.

4.2. Cooling boundary conditions

The cooling system is done by a number of pinholes parallel to each other (circular perforations at the jaws with an 8 mm diameter). A 6x1 mm inner tube made of stainless steel is inserted into the each pinhole and wires are around the inner tube in order to enhance the convection heat transfer (see Figures 6 and 14d). The wire produce high gain in enhanced cooling but require higher pressure drops for a given flow as compared to the empty annuli (see Figure 7).

All the crotch absorbers are cooled by water at 23ºC. The velocity in the cooling channels is kept in the range not more than 3 m/s in order to keep flow–induced vibrations within acceptable levels. This limit for the velocity is conservative if we compare with the experimental investigations made at APS [10], in which case a velocity of 15 ft/sec (4.6 m/s) is considered to be acceptable. That conclusion is based on some erosion–corrosion test for copper and Glidcop channels in high–purity water. At the same synchrotron, as design criteria the velocity in the cooling channels is kept in the 3 – 5 m/s range in order to reduce the induced vibrations [11].

The thermal hydraulic calculations are based on the experimental correlations from SLS [12] (see Figures 6 and 7). Because of the good experimental results for the convective heat transfer coefficient "*h*" the configuration "pitch height 35 mm" has been chosen for the final design. For the FEA calculations two values of the coefficient "*h*" are evaluated: (i) Assumption 1: h = 10,000 W/m^{2o}C (conservative approach) and (ii) Assumption 2: h = 15,000 W/m^{2o}C (more realistic approach). For the latest the mass flow at the pinhole is around 28 gr/s (1.7 l/min) and the pressure drop for one pinhole 45 cm length equals around 0.43 bar. In the case of the critical crotch absorber type 3, the calculated pressure drop is very high because there are 4 pinholes in series connection. Our preliminary estimations for the pressure drop based on the experimental correlations from SLS have been verified in an experimental setup made at ALBA (see section 5).

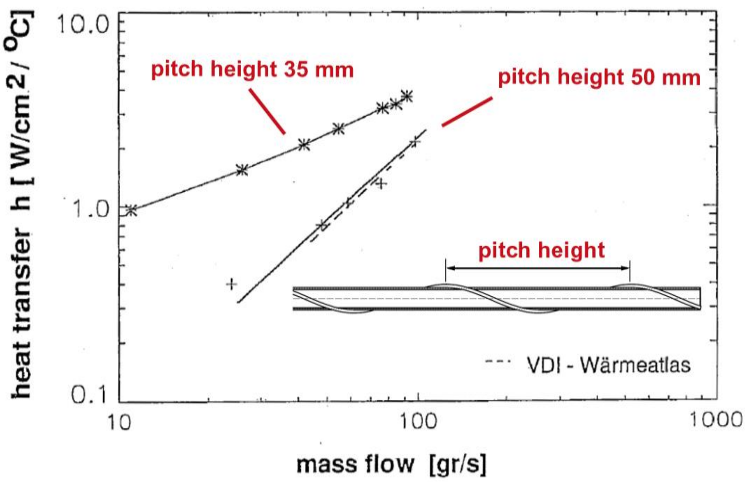

Figure 6 Experimental correlations for the cooling pinhole type [12]. Dependence of the convective heat transfer coefficient "*h*" on the mass flow for two pitch height: 35 and 50 mm.

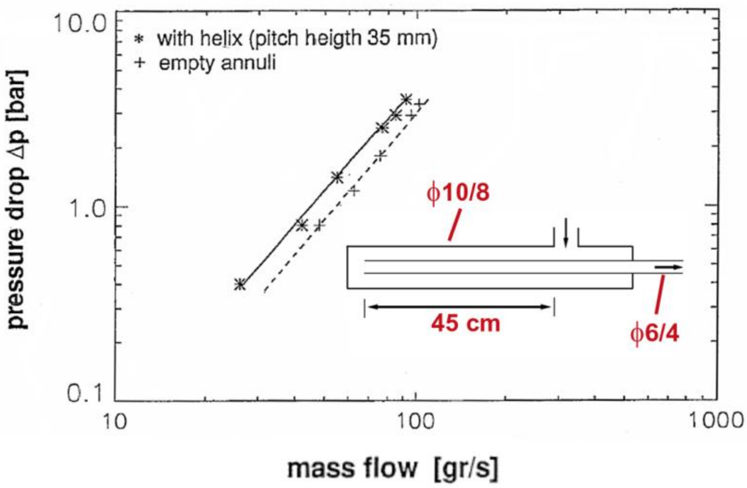

Figure 7 Experimental correlations for the cooling pinhole type [12]. Dependence of the pressure drop on the mass flow for two cases: (i) with helix (pitch height 35 mm) and (ii) empty annuli.

4.3. Finite Element Analysis (FEA)

The thermal–stress analysis of the presented crotch absorbers has been performed based on Finite Element Analysis (FEA). The calculations of the stress, strain and temperature distribution were performed based on linear elastic analysis. The ANSYS software has been used to achieve this target.

With respect to the power load applications three trajectories for the bending magnet radiation are investigated: (i) Nominal, (ii) Lower misalignment and (iii) Upper misalignment. For the nominal case, the crotch absorber is mechanically aligned on the theoretical position. As for the misalignment cases, they are the cases were the beam do not hit in the middle of the absorber, which cause extreme situations for the power load, this misalignment includes the upper/lower limit tolerance of alignment and fabrication and the maximum deviation of the beam.

The physical properties for Glidcop® Al-15 LOX have been considered as a function of the temperature (because for the critical absorbers the maximum temperature is more than 200ºC) (see APS reference [13]), however constant material properties have been introduced for those absorbers made of copper, as the maximum temperature is around 130ºC.

Because of the vertical extent of the radiation is small, it is necessary to generate an extremely fine mesh at the footprint. Variable meshing has always been preferred in order to have a much thinner mesh in the region with heat load (high temperature gradient and high stress and strain) than in the other regions. For the FEA calculations the optimal size and number of the elements in meshing have been investigated in order to guarantee that the results are in the asymptotic range, that is, they are independent of the mesh. Figure 8 shows an example of the variable meshing used for the FEA calculations.

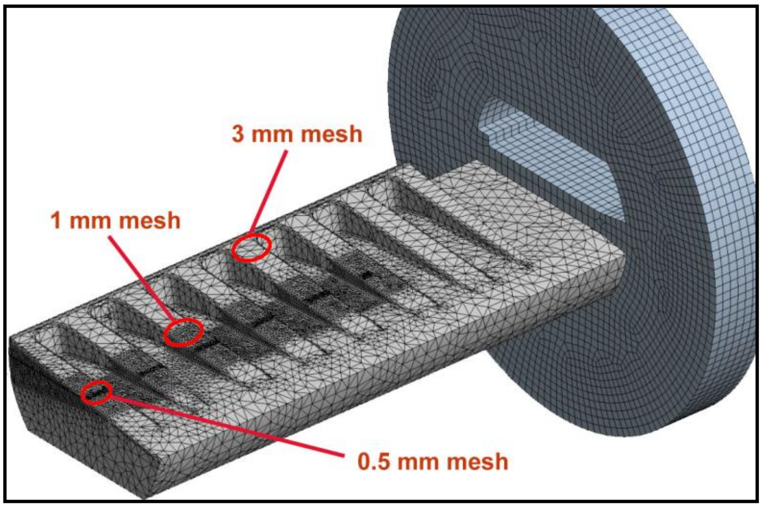

Figure 8 Example of the mesh size used for the simulations. For the numerical optimization the mesh is refined at the footprint.

For all the FEA studies only the upper jaw is simulated. This jaw is subject to the maximum power load conditions, in comparison with the lower jaw. Adiabatic boundary conditions are applied on to all surfaces for thermal analysis except for the water cooling interfaces and the footprint heating area. Artificial mechanical constraints were applied to the FEA structural model because the calculated stress is thus pure thermal stress.

Table 3 shows the results of the FEA for the maximum overall temperature on the crotch absorber $T_{ov,max}$ (ºC), the maximum cooling water temperature $T_{c,max}$ (ºC), the maximum von Mises stress (MPa) and the maximum total strain (%) on the different types of the crotch absorbers. Figure 9 shows the FEA results for crotch absorber type 3 under assumption 1. The results show that temperatures decrease with increasing the coefficient "*h*". However the change in "*h*" has no significant impact on the stress and strain.

Table 3: Summary of the FEA results for the three types of the absorbers under assumptions 1 and 2.

Assumption 1 (h = 10,000 W/m^2°C)				
Absorber Type	***$T_{ov,\,max}$ (°C)***	***$T_{c,\,max}$ (°C)***	***Stress (MPa)***	***Strain (%)***
1	*91.2*	*62*	*21.8*	*0.019*
2	*127.5*	*66*	*45.8*	*0.044*
3	*312.8*	*91.3*	*112.3*	*0.10*

Assumption 2 (h = 15,000 W/m^2°C)				
Absorber Type	***$T_{ov,\,max}$ (°C)***	***$T_{c,\,max}$ (°C)***	***Stress (MPa)***	***Strain (%)***
1	*79*	*51*	*20*	*0.018*
2	*109*	*50*	*46.3*	*0.04*
3	*290*	*70*	*111.9*	*0.098*

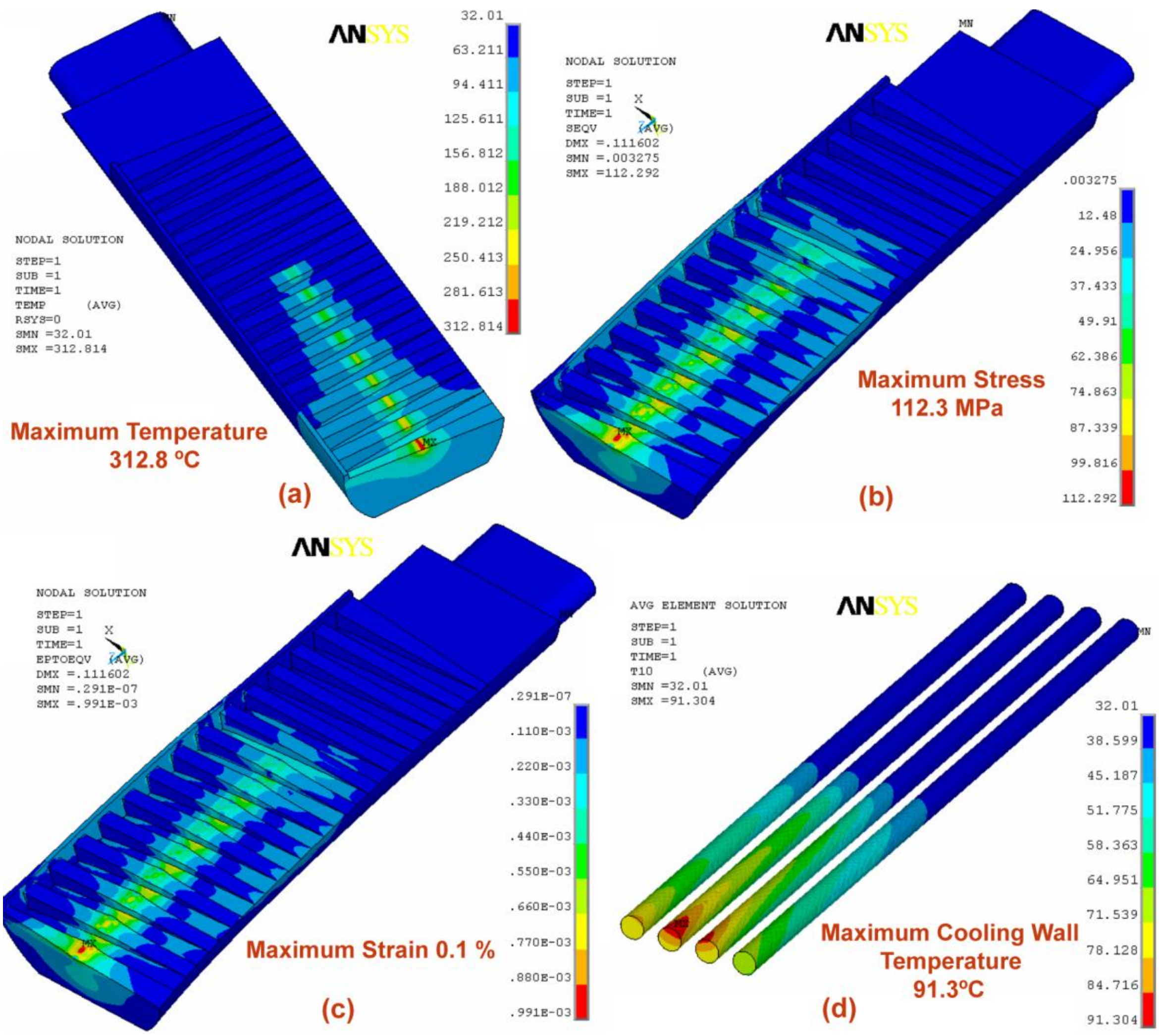

Figure 9 FEA results for crotch absorber type 3 under conservative assumption 1. (a) Temperature distribution. (b) Von Misses stress distribution. (c) Strain distribution. (d) Temperature distribution at cooling wall.

Based on the FEA results, the material for each type of the crotch absorber has been chosen. In order to have more than $1x10^5$ cycles for the crotch absorbers, the types 1 and 2 will be manufactured using OFHC copper, and to guarantee the same number of cycles for type 3, Glidcop® Al-15 will be used.

The real behaviour of copper is elasto-plastic, i.e. considering the stress-strain curve for the material (in case the material reached the yield value then the plastic behaviour of the material will be considered in obtaining the stress and the strain values). Elasto-plastic analysis has been performed for absorber type 2 (OFHC copper) to estimate the real stress and strain on the absorber and to guarantee that it is safe to use copper for this type. The maximum stress and strain from these analyses was 36 MPa and 0.05 %, respectively, the results are within ALBA design criteria.

For the comparative analysis of the nominal and misalignment cases the geometrical models to be simulated were similar for all the cases: tooth thickness = 10 mm and tooth inclination = 8.8º. The FEA results are summarized in Table 4. The thermal–stress simulations show that the maximum temperatures ($T_{ov,max}$ and $T_{c,max}$) for the misalignment cases are higher than the nominal case but reasonable; the main reason is that for misalignment cases the footprint is far away from the cooling tubes in comparison with the nominal case. The results for the stress and strain become worst for the upper misalignment if we compare with the nominal and lower misalignment, and the results are much better for the lower misalignment. The main reason is in the thickness of the tooth: for the lower case the radiation collides in a small thickness after tooth (due to the teeth inclination), then globally this part absorbs less power than the nominal and upper misalignment cases in the same tooth, and in addition the reduced thickness is helpful for the mechanical "relaxation" of the material.

Table 4: Summary of the FEA results for the crotch absorber type 3 (tooth thickness = 10 mm, tooth inclination = 8.8º) under nominal and misalignment conditions for assumptions 1 and 2.

Assumption 1 (h = 10,000 W/m²ºC)				
BM radiation trajectory	***$T_{ov, max}$ (°C)***	***$T_{c, max}$ (°C)***	***Stress (MPa)***	***Strain (%)***
Nominal	*308*	*95*	*195*	*0.173*
Upper Misalignment	*349.3*	*137.5*	*237*	*0.211*
Lower Misalignment	*365.3*	*114*	*163.6*	*0.148*

Assumption 2 (h = 15,000 W/m²ºC)				
BM radiation trajectory	***$T_{ov, max}$ (°C)***	***$T_{c, max}$ (°C)***	***Stress (MPa)***	***Strain (%)***
Nominal	*285*	*73*	*193*	*0.169*
Upper Misalignment	*322*	*110*	*234*	*0.206*
Lower Misalignment	*340*	*89*	*162*	*0.145*

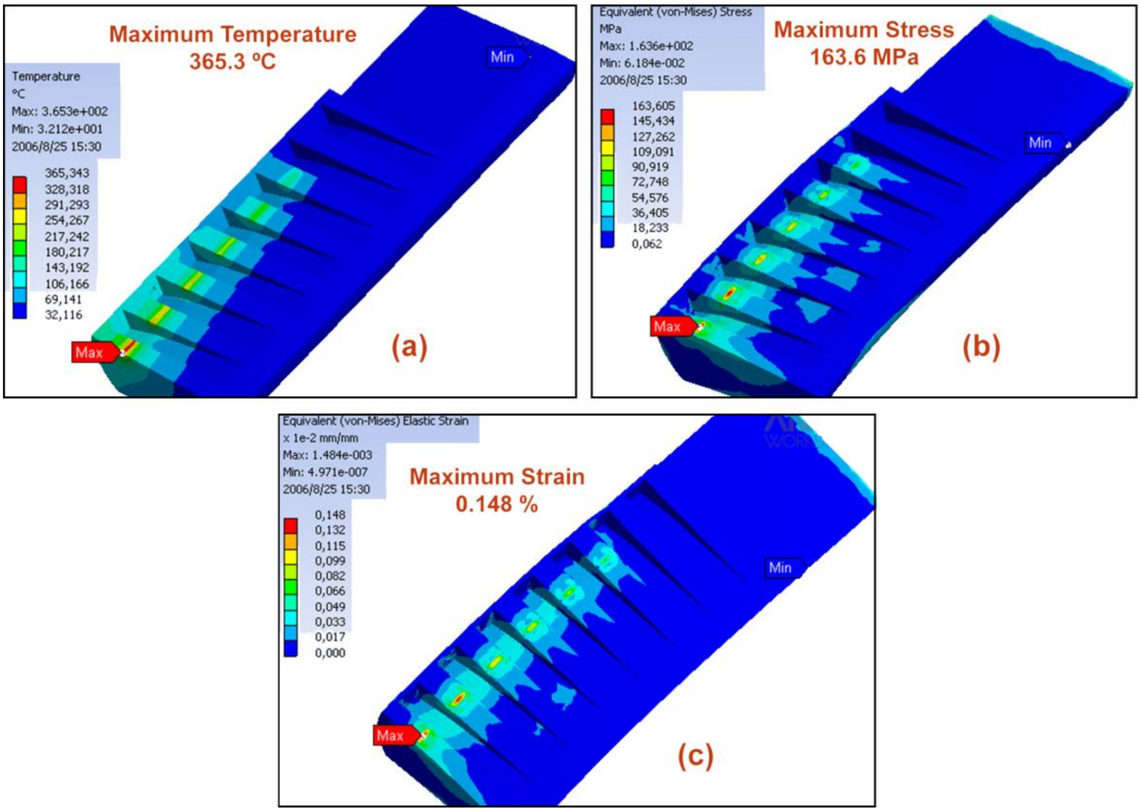

Figure 10 FEA results for crotch absorber type 3 under lower misalignment effect and assumption 1. (a) Temperature distribution. (b) Von Misses stress distribution. (c) Strain distribution.

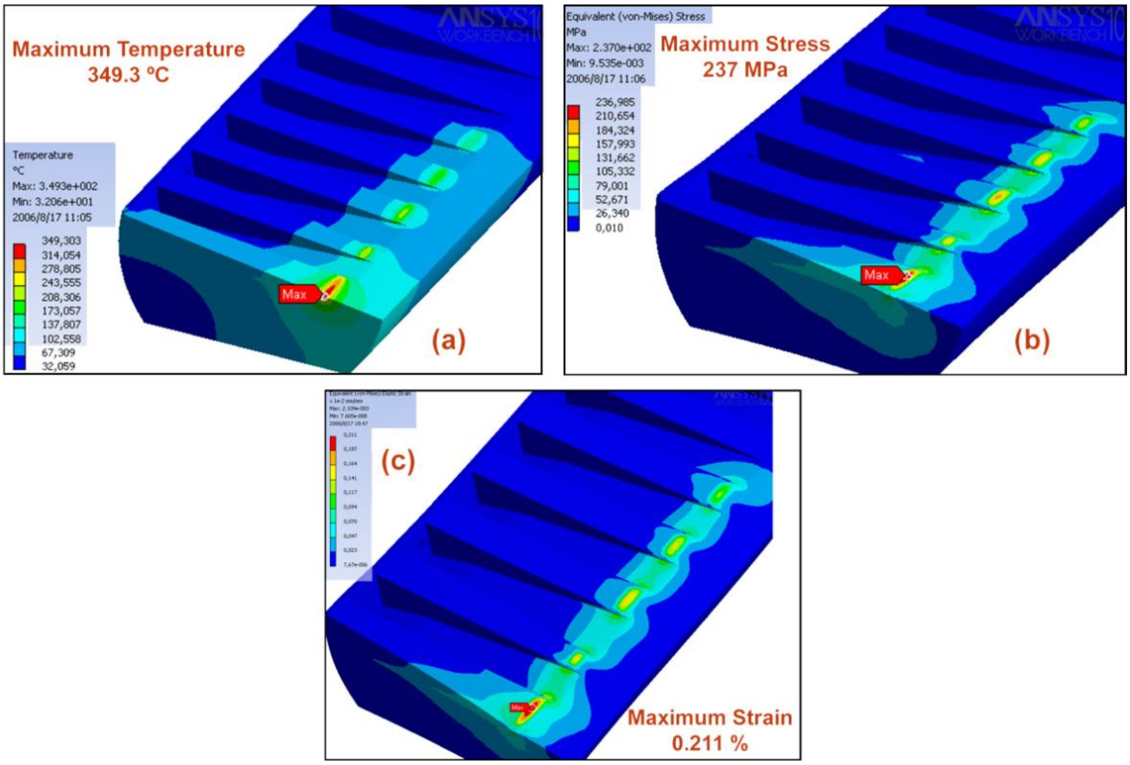

Figure 11 FEA results for crotch absorber type 3 under upper misalignment effect and assumption 1. (a) Temperature distribution. (b) Von Misses stress distribution. (c) Strain distribution.

4.4. Optimization of the crotch absorbers: study based on the critical crotch absorber type 3

The optimization analysis has been carried out for the critical crotch absorber type 3. The investigation was based on two geometrical issues: (i) The vertical inclination of the tooth (α): when a surface is inclined, the area is increased by a factor of $1/\sin(\alpha)$, where α is the angle between the plate and the incident beam, and (ii) The thickness of the tooth (δ): a small thickness is useful for the mechanical "relaxation" of the samples subject to heat loads. Table 5 shows the cases under investigation and their results. For the angle α there is a minimum value (5.7º) which guarantee that all the radiation collide in the teeth. For each assumption the tendency of the results is similar: the temperatures decrease in modest manner with decreasing the inclination of the tooth and the stress and strain decrease considerably with decreasing the thickness of the tooth. The comparison between assumptions 1 and 2 shows that the temperature decrease when the coefficient "*h*" increase, but there is no significant variation on the stress and strain.

Table 5: Comparative studies for the three models of the critical crotch absorber type 3. The geometrical differences between them are in the thickness (δ) and the inclination (α) of the tooth.

Assumption 1 (h = 10,000 W/m²ºC)				
Models	***$T_{ov,\,max}$ (°C)***	***$T_{c,\,max}$ (°C)***	***Stress (MPa)***	***Strain (%)***
1) δ = 10 mm, α = 8.8º	*308*	*95*	*195*	*0.173*
2) δ = 6 mm, α = 6.6º	*301*	*92.5*	*107*	*0.094*
3) δ = 4 mm, α = 5.7º	*289*	*89*	*96*	*0.081*

Assumption 2 (h = 15,000 W/m²ºC)				
Models	***$T_{ov,\,max}$ (°C)***	***$T_{c,\,max}$ (°C)***	***Stress (MPa)***	***Strain (%)***
1) δ = 10 mm, α = 8.8º	*285*	*73*	*193*	*0.169*
2) δ = 6 mm, α = 6.6º	*282*	*71*	*106*	*0.092*
3) δ = 4 mm, α = 5.7º	*267*	*68*	*96*	*0.08*

4.5. Optimization of the end of the pinhole based on CFD techniques

According to the FEA results, the peak for temperature, stress and strain are located close to the end of the pinhole. Then the cooling performance in this region becomes important. In order to find the best geometrical design at this part a study of the fluid behaviour was done using Computational Fluid Dynamic (CFD) techniques. Three cases have been investigated (see Figure 12): (i) Case 1: flat, (ii) Case 2: concave inside, and (iii) Case 3: concave outside.

The behaviour of the velocity field represented at Figure 13 is representative for a wide range of the mass flow. In Figure 13 the results correspond to mass flow condition equals 12.46 gr/s. For all cases the velocity field intensity for cases 2 and 3 are higher than the case 1, then the heat transfer enhance is much better for cases 2 and 3 than the case 1. The distribution maps shows stagnation points by the end of the pinholes for cases 2 and 3. This can be reduced by having fillets (smooth groove) by the end. The final decision for the cases 2 or 3 and the inclusion of fillets depends on manufacturing limits.

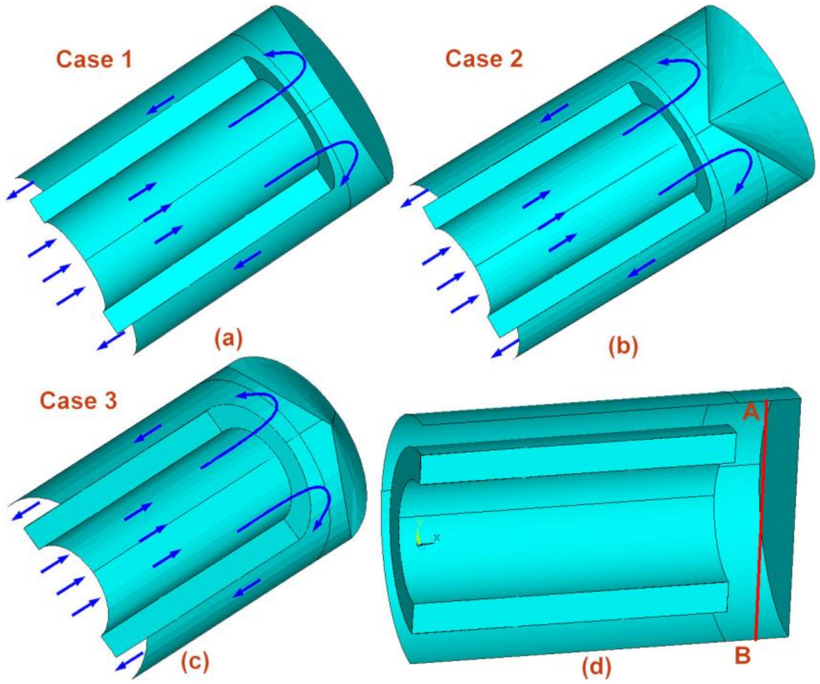

Figure 12 Cases to be analyzed with Computational Fluid Dynamics: (a) Case 1: flat, (b) Case 2: concave inside and (c) Case 3: concave outside. (d) For the comparative study the velocity profiles are analyzed in various positions at the end of the pinhole, like the line represented by AB.

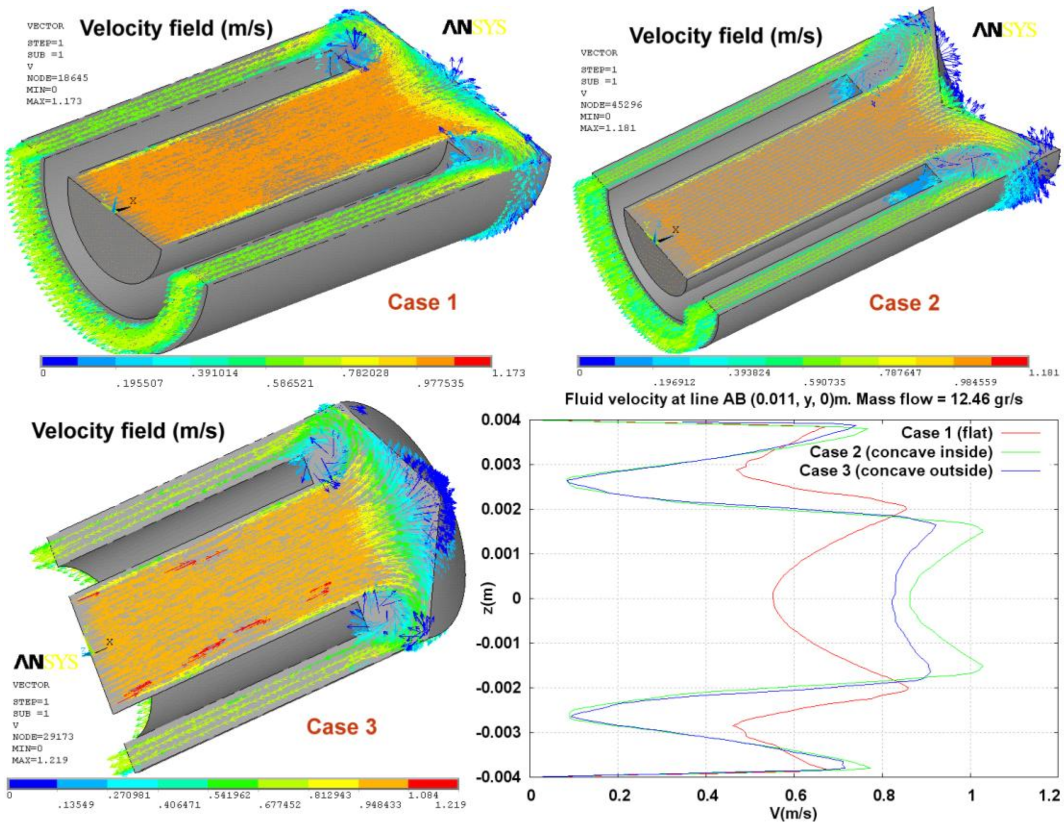

Figure 13 Velocity distributions for the three cases under investigation. The velocities curves are an example of the comparative study. The results showed that the velocity field intensity for cases 2 and 3 are higher than the case 1.

5. Hydraulic Test for Real Models

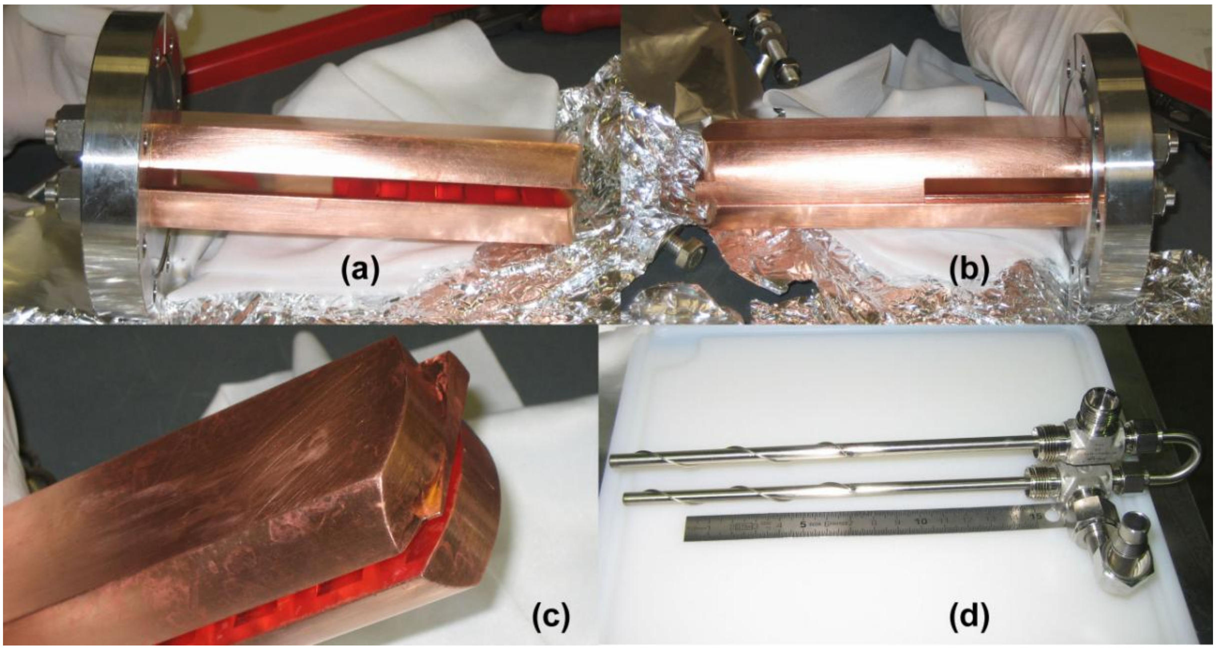

Figure 14 Pictures of a real crotch absorber at ALBA (type 1). (a) Position which receive directly the BM radiation, in between the jaws. (b) Back side of the crotch absorber. (c) Detail of the end of the crotch absorber with the “special tooth”. (d) The inner tube to be inserted into the pinholes (circular perforations at the jaws), wires are around the inner tube in order to enhance the heat transfer.

As part of the verification of the design, the real crotch absorbers (see Figure 14) are recently subject to some hydraulic tests. At ALBA an experimental setup has been prepared in order to verify the experimental correlations give by reference [12] (see Figures 6 and 7). There are some reasons to do this verification test: (i) The correlations give by reference [12] correspond to an experimental channel 45 cm length, but there were not information about the contribution of the pressure drop due to the end of the pinhole, (ii) There is no information about the real length for the wire around of the inner tube, (iii) There is no information about the uncertainties of the experimental measurements. In addition, the pressure drop test is helpful for the detection of the possible problems in the cooling circuit.

For this section, part of the quantification of the pressure drop is presented, which information will be useful for the final optimization of the hydraulic circuits at ALBA storage ring, and obviously for the performance of the crotch absorbers. Table 6 shows the first experimental results obtained at ALBA. The percentage differences are in agreement with our preliminary conservative predictions. That means if a posterior increment in the flow rate is necessary it will not generate problems in the pressure drop and it will be possible obtain convective heat transfer coefficients much higher than the assumption 2.

Table 6: Verification of the pressure drop Δp at the pinholes in ALBA crotch absorbers.

Flow rate = 1.7 l/min			
Absorber	***Δp (bar) Reference [12]***	***Δp (bar) ALBA***	***Difference (%)***
Type 1	*0.32*	*0.36*	*12.5*
Type 2.3	*0.42*	*0.43*	*2.4*

6. Conclusions

Based on ALBA design criteria, all the crotch absorbers are in safe range. For ALBA, the cycles for fatigue based on the strain values for OFHC copper and Glidcop® Al–15 are the design criteria being followed, and to guarantee that the absorbers are safe for the life time of the machine, the material have been chosen for values more than $1x10^5$ cycles of OFHC copper (strain < 0.1%) and over $1x10^5$ cycles for Glidcop® Al–15 (strain < 0.2%). The mechanical design of the absorbers has been done in a way which will guarantee the optimum performance, this include the lowest temperature, strain and stresses on the absorbers.

Because of the good results obtained in the optimization analysis, the thickness and the inclination angle for the teeth of the crotch absorbers type 3 are 6 mm and 6.6º respectively.

Several safety factors were considered during the design, the main safety factor is the number of cycles considered acceptable for the life time of the absorbers. The other safety considerations are: (i) The machine parameters used for achieving the power inlet were based on the design parameters (e.g. the beam current = 400 mA, the beam energy = 3 GeV…etc), (ii) Rectangular approximation for the inlet power in the absorbers (i.e. considering the power as a rectangle which has the same surface area under the Gaussian power profile and having the maximum angular power density) and (iii) The conservative fluid conditions.

7. References

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